AD-A077 193 NAVAL RESEARCH LAB WASHINGTON DC F/G 17/1

SONAR TRANSDUCER RELIABILITY IMPROVEMENT PROGRAM FY 1979.(U)

OCT 79 R W TIMME

UNCLASSIFIED NRL-MR-4058 SBIE-AD-E000 332 NL

| OF |

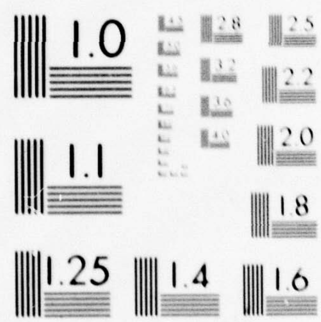
AD A077193

END

DATE FILMED

1-80

DDC



MICROCOPY RESOLUTION TEST CHART

NATIONAL BUREAU OF STANDARDS 1963-A

AD-E 000 332

NRL Memorandum Report 4058

Sonar Transducer Reliability Improvement Program FY 79

Fourth Quarter Progress

R. W. TIMME

Materials Section
Transducer Branch
Underwater Sound Reference Detachment
P.O. Box 8337, Orlando, Fl 32856

12

LEVEL III

October 1, 1979

NAVAL RESEARCH LABORATORY
Washington, D.C.

Approved for public release; distribution unlimited.

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER NRL Memorandum Report 4058	2. GOVT ACCESSION NO.	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) 6 Sonar Transducer Reliability Improvement Program FY ~~Fourth Quarter Progress~~ 1979.		5. TYPE OF REPORT & PERIOD COVERED Interim report on a continuing problem.
		6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) 10 Robert W. Timme		8. CONTRACT OR GRANT NUMBER(s) 14 NRL-MR-4058
9. PERFORMING ORGANIZATION NAME AND ADDRESS Underwater Sound Reference Detachment Naval Research Laboratory P.O. Box 8337, Orlando, FL 32856		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS NRL Problem S02-43.801 Program Element 64503N
11. CONTROLLING OFFICE NAME AND ADDRESS		12. REPORT DATE 11 1 Oct ~~ober 1~~979
		13. NUMBER OF PAGES
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office) 12 54		15. SECURITY CLASS. (of this report) UNCLASSIFIED
		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited

9 Quarterly progress rept. no. 4,

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

The Sonar Transducer Reliability Improvement Program (STRIP) is sponsored by NAVSEA 63XT

18 SBIE

19 AD-E000 332

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Transducers	Connectors	Water Permeation
Corona	Noise and Vibration	Environmental Tests
Transducer Fluids	Pressure Release	
Encapsulation	Noise	
Cables	Material Evaluation	

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

Progress accomplished during the fourth quarter of FY79 in the Sonar Transducer Reliability Improvement Program is reported. Each of the eight program tasks is discussed in some detail. The most significant aspects are the discovery of a parasitic current phenomena, different from corona, that may lead to a diagnostic test for transducers, piece-part testing in support of composite unit accelerated life testing of transducers to identify and cure failures, and five published reports on projects successfully accomplished.

DD FORM 1 JAN 73 1473 EDITION OF 1 NOV 65 IS OBSOLETE

S/N 0102-LF-014-6601

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

251 950 Du

CONTENTS

Page

Sonar Transducer Reliability Improvement Program

NRL Problem 82 S02-43

FY79 Fourth Quarter Report

1. INTRODUCTION

1.1. PROGRAM OVERVIEW

The general objective of this program is to perform relevant engineering development which addresses the operational requirements for fleet transducers for active sonar, passive sonar, surveillance, counter-measures and deception devices, navigation, and acoustic communications. The approach is to develop, test and evaluate improved transducer design, materials, components, and piece parts that will meet specified requirements in the operational environment during the entire useful life of the transducer. Standards will be prepared to ensure that results obtained during preliminary testing will be obtained consistently in production. This program should result in improved performance and reliability and reduced costs through better utilization and a more comprehensive characterization of materials and design data. The program goals are as follows:

- Reduction in transducer replacement costs

  Goal - less than 9% of population replaced each year with no automatic replacements at overhaul

  Threshold - less than 18% of population replaced each year

- Improvement in transducer reliability

  Goal - less than 1% of population failures each year

  Threshold - less than 3% of population failures each year

- Improvement in transducer receiving sensitivity

  Goal - less than ±1 dB variation from the specified value over operational frequency band

  Threshold - less than ±2 dB variation from the specified value over operational frequency band

- Reduction in transducer radiated self-noise

  Goal - 30 dB reduction
  Threshold - 20 dB reduction

The Sonar Transducer Reliability Improvement Program (STRIP) is a part of Program Element 64503N. Major task areas with specific objectives to achieve the program goals have been described in the Program Plan and include:

Task Area A. Encapsulation Methods
Task Area B. High Voltage Engineering
Task Area C. Cables and Connectors
Task Area D. Transducer Material Standards
Task Area E. Environmental Test Methods
Task Area F. Noise and Vibration
Task Area G. Transducer Tests and Evaluation

The FY79 Program Plan for STRIP has been funded at the $495 K level. The specific tasks and their Principal Investigators for FY79 are listed below:

	TASK	PRINCIPAL	INVESTIGATOR
A-1	Fluids and Specifications	NRL	C.M. Thompson
B-1	Corona Abatement	NRL	L.P. Browder
C-1	Cables and Connectors	TRI	D.E. Glowe (D. Barrett)
D-1	Materials Evaluation	NUSC	C.L. LeBlanc
E-1	Standard Test Procedures	NOSC	G.L. Kinnison (J. Wong)
F-1	Noise and Vibration	NOSC	C. Bohman
G-1	Sleeve-Spring Pressure Release	TRI	R.L. Smith (D. Barrett)
G-2	Test and Evaluation	NRL	A.M. Young
G-3	Engineering Documentation	NWSC	D. Moore (D.J. Steele)

1.2. SUMMARY OF PROGRESS

During the fourth quarter of FY79, efforts in the various tasks of STRIP have resulted in progress toward the program goals as summarized below:

- A low-frequency parasitic current phenomena, different than corona, has been observed that is directly correlated to PZT ceramic voltage breakdown. This may lead to a straight-forward diagnostic test for transducers. See Section 3.3.2.

- The lifetime function for high-voltage drive of one thickness of PZT ceramic has been measured using insulator gases of dry and wet air, sulfur hexafluoride (SF_6), and perfluoroethane (C_2F_6). See Section 3.3.1.

- Calculations which quantify the importance of the ideality condition of the approach to the water solubility limit of the fill-fluids have been submitted for publication. See Section 2.3.2.

- A study on the interactions of sea water and transducer rubbers has resulted in an interim technical report entitled "The Effect of Seawater on Polymers." See Section 2.3.1.

- Laboratory testing of piece-parts of the TR-316 transducers has successfully identified the specific failure modes that caused the composite unit to fail first article testing. Recommendations for solving the problem have been made and proven. See Section 6.3.1.

- A technical report entitled "Results of Radiated Self-Noise Measurements of TR-215 Transducer," NOSC TN 647, has been written. See Section 7.3.1.

- A technical report entitled "Development and Application of a Transducer Radiated Self-Noise Criterion Based on Optimal Detection Theory," NOSC TN 397, has been written. See Section 7.3.1.

- A technical report entitled "Development of a Low-Noise Pressure Release Sleeve-Spring for the TR-155 Transducer" has been written by Texas Research Institute, Inc. See Section 8.3.

- NAVSEA has released 48 DT-168B hydrophones from the AN/BQR-2 sonar of the USS Stonewall Jackson (SSBN 634) to STRIP. The hydrophones, after acoustic testing, will be sent to the Naval Weapons Support Center, Crane, IN, for failure analysis testing and as a verification test for the CUALT concept.

1.3. PLANS

The Program Plan for FY80 STRIP has been approved by NAVSEA at the $495 K level. The difference between this and the proposed level ($900 K) has been resolved by task elimination and task transferral. The funding level for FY80 will be committed among the following tasks:

	TASK	PRINCIPAL	INVESTIGATOR
A-1	Fluids and Specifications	NRL-USRD	C.M. Thompson
A-2	Encapsulants	NRL-USRD	C.M. Thompson
B-1	Corona Abatement	NRL-USRD	L.P. Browder
C-1	Handbook for Harness Design	Contractor	
C-2	Standard for O-Ring Installation	APL-Univ. of Washington	C. Sandwith
D-1	Alternative Materials, Plastics	NWSC	D. Moore
D-2	Pressure Release Materials	NUSC	C. LeBlanc
E-1	CUALT	NOSC	J. Wong
E-2	ALT Verification	NWSC	D.J. Steele
F-1	Failure Modes Due to Water	Contractor	
F-2	Shock Hardened Pressure Release	Westing-house	C.J. Wilson
F-3	Reliability and Life Prediction Specification	Contractor	
F-4	Engineering Documentation	NRL-USRD	R.W. Timme

Productivity for FY80 is expected to include the following

- Task A - Report on transducer fill-fluids
- Task A - Interim report on encapsulation materials
- Task B - Report on study of corona and arc formations
- Task B - Report on ceramic lifetime function
- Task C - Final report on unshielded cable strength and backshell leakage
- Task C - Handbook for connector and cable harness design
- Task C - Standard for O-ring installation
- Task D - Final report on pressure release materials and transducer fluids
- Task D - Report on measurement technique for pressure release materials
- Task D - Interim report on water permeation of elastomers
- Task E - Final report on accelerated life testing procedures for BQS-8/10/14/20
- Task E - Report on transducer diagnostic test procedures for accelerated life testing of SQS-56

- Task F - Report on failure modes due to water in transducers
- Task F - Report on shock hardened pressure release material
- Task F - Report on water permeation lifetime function
- Task F - Interim report of progress on a reliability standard
- Task F - Four quarterly reports on program progress

The major change in the STRIP is the transferral of the Noise and Vibration Task Area to the Sonar Transducer Extraneous Noise (STEN) Program. The STEN Program is a new RDT&E engineering development program which was established by NAVSEA at the request of CNO to study, analyze, and evaluate potential noise sources in transducers. To avoid possible duplication of effort the noise task previously carried as a part of STRIP will be a part of the STEN Program starting in FY80.

1.4. REPORT ORGANIZATION

The remaining sections of this quarterly report will discuss the objectives, progress, and plans for the specific tasks included in the STRIP.

2. TASK A-1 - TRANSDUCER FLUIDS AND SPECIFICATIONS

C. M. Thompson - NRL-USRD

2.1. BACKGROUND

A material to be used for filling a sonar transducer must meet a wide variety of specifications. The requirements imposed by the electrical nature of the device include high resistivity, high dielectric constant, as well as resistance to corona and arc discharges. The water environment of the transducer necessitates low water solubility and other attractive solution properties. In addition, the fluid must maintain its electrical and other properties in the presence of any water which permeates the covering. The acoustic requirements are a close acoustic impedance match with sea water and resistance to cavitation at high-drive levels. Other obvious properties include compatibility with other components, stability to degradation, suitable surface tension, and viscosity.

With such a wide variety of requirements, it is not surprising that compromises have to be made. The most commonly used fluid for many years has been castor oil. This use is in spite of its high viscosity. Each of the fluids proposed, so far, as a replacement has serious drawbacks. Silicone oils tend to creep onto and wet all of the surfaces of the transducer. This greatly complicates bonding the components together. Polyalkylene glycol (PAG) has the disadvantages of a high water solubility and low electrical resistivity. The various hydrocarbon liquids have too low an acoustic impedance and are frequently incompatible with the various plastics and rubbers in the transducer. Further research is necessary to find and qualify fill-fluids which represent the best match to all the requirements imposed upon it.

2.2. OBJECTIVES

The objectives of this task are:

- To find plausible new transducer fill-fluids which combine all the best properties. Candidates include: hydrophobic-polyethers, sterically protected esters, chlorine - or fluorine - containing hydrocarbons, methyl alkyl silicones, and possibly aromatic hydrocarbons.
- To apply the criteria developed during the PAG and castor oil testing to the most promising candidate fluids.
- To conduct a preliminary investigation into the mechanics and kinetics of the sea water-polymer interactions.

2.3. PROGRESS

2.3.1. The study of sea water-polymer interactions which was begun during the 3rd quarter FY79 was concluded. The results obtained after 92 days of testing are shown in Table 2.1.

GENERIC TYPE	FORMULATION	TYPE OF EXPOSURE	E_a	A
Polychloroprene	Neoprene W	Sea Water	58.6 kJ/mol	2.49×10^3
		Fresh Water	56.4 kJ/mol	2.02×10^3
Polychloroprene	Neoprene 5112	Sea Water	67.8 kJ/mol	5.69×10^3
Chlorobutyl	H862A	Sea Water	82.8 kJ/mol	1.65×10^3

Table 2.1 - Rate of Water Diffusion

Where the values for the energy of activation, E_a, and statistical factor, A, are substituted into the equation:

$$\left(\frac{\Delta m}{m_o}\right)^2 = A \cdot t \cdot \exp(-E_a/RT) \qquad (2.1)$$

where $\frac{\Delta m}{m_o}$ is the fractional weight gain,

t is the time in hours,

R is the gas law constant (8.314 J/mole °K), and

T is the temperature in degrees Kelvin.

The significance of these results is that for at least some materials, the rate of degradation of the properties may be accelerated simply by an increase in temperature.

Since the change in weight of a sample is not an absolute test, it cannot be used exclusively to predict the useful lifetime of a polymer. However, failure in an end-use test is very probably related to the weight change of the polymer on exposure to water. This allows a prediction of the amount of time until the polymer fails. For example, if a given significant loss of tensile strength occurs with a 10% weight gain (must be determined experimentally) for Neoprene W, then the time it would take for failure to occur in sea water at 25°C would be 8.6 years. This was calculated using Eq. (2.1). For polymers that do not interact by a diffusion process, estimates of the lifetime can be made using the graphs of the weight change with time which are given in the published memorandum report (NRL Memorandum Report 4097).

Further work on this project will transition into Task D of STRIP in FY80.

2.3.2. One little recognized function of the fill-fluid is to resist the permeation of water into the transducer. Calculations have recently been carried out which quantify the effect of the ideality of the fill liquid upon the rate of water permeation into the transducer. The deviation from ideality (Henry's law) was first closely approximated by a parabolic equation. The coefficients of the equation were chosen to represent castor oil (positive deviation), PAG (negative deviation), and an oil with no deviation. The parabolic Henry's law equation was substituted into the permeation equation, a change of variables was performed, and the resulting equation was integrated. Variables were chosen to represent a typical Neoprene-booted sonar transducer. Curves were plotted from the resulting equation which show the variation of water content with time. A useful way of comparing the rates of water permeation is to calculate the times required for sufficient water to permeate so that water will precipitate if the temperature should then be lowered by 5°C. The time to that point is 12,000 hours for a transducer filled with an oil which is ideal with Henry's law. Negative deviation from Henry's law (as shown by PAG) causes this time to decrease to 8,000 hours. Positive deviation (as shown by castor oil) causes the time to increase to 28,000 hours. Details of these derivations and calculations can be found in a report entitled "Permeation into Containers Filled with Non-Ideal Oil," which has been submitted for publication. Advanced copies may be obtained from the author.

2.3.3. In order to provide some unity in the selection of transducer fill-fluids, a flow chart was devised which incorporates the best current information, along with some guesses about the future. This is shown as Fig. 2.1. The values presented are the result of extensive experience with fill-fluids at USRD, and of consultation with sonar engineers from other laboratories. Of course, each boundary between acceptable and not acceptable is not hard and fast, but must be considered for each application. Comment is solicited from interested persons about the magnitude of the boundary values and about any missing criteria.

It is interesting and illustrative to consider the previously discussed methyl alkyl silicones (MAS) within the format of this flow chart. As discussed in the 2nd and 3rd quarter FY79 STRIP reports, SF1147, a typical MAS, easily passes the first six decisions. Attenuation of high frequency sound has been reported as being a problem with the dimethyl silicones and likely will also be a problem with MAS. MAS has a low H_2O-solubility limit (<0.05% reported by manufacturer) and is stable to both hydrolysis and oxidation under sonar transducer conditions.

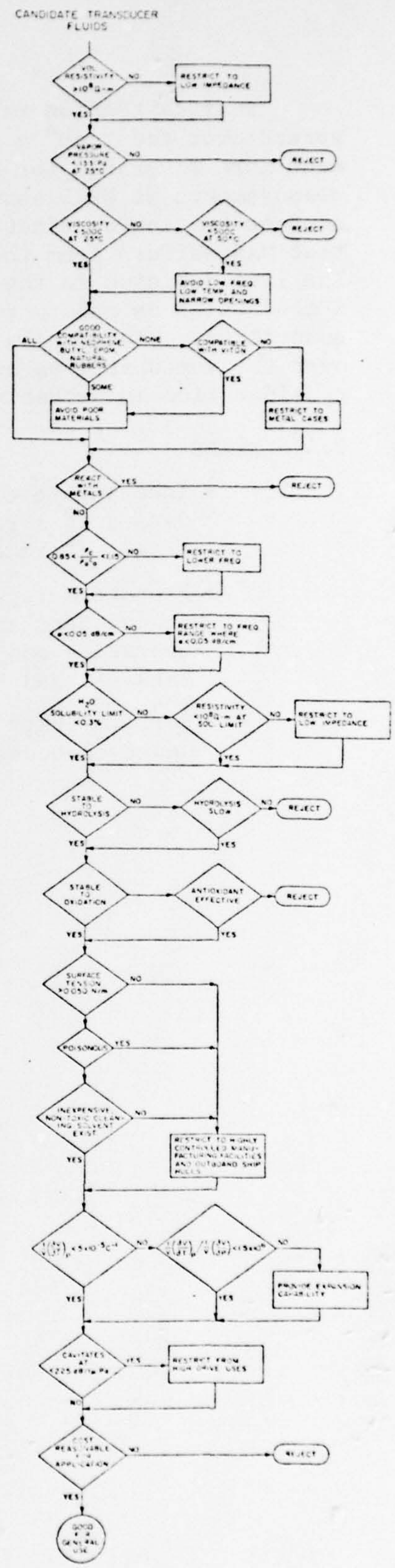


Fig. 2.1 - Flow Chart for Sonar Transducer Fluid Selection

Surface tension is a measure of the tendency of a liquid to spread over and "wet" a surface. This property was expected to be much more favorable for MAS than for dimethyl silicones. However, measurements at USRD show MAS to have approximately the same surface tension as dimethyl silicone. At this point, it appears that MAS suffers from the same disadvantage as dimethyl silicones. The last decision in the flow chart is also damning for MAS. SF1147 which is manufactured by GE sells for $7.00/pound in drum quantities. Since there are no clear-cut advantages of SF1147 over the somewhat less expensive dimethyl silicones, further consideration is probably not warranted.

2.4. PLANS

- Incorporate comments from readers and new data into a report on transducer fluid decision tree. (December 1979)
- Prepare a report on water permeation into sonar transducers and the effect this has on operation and lifetime. (Cooperative between Task A-1 and F-1)
- Perform tests on modified PTMG developed under in-house 6.1 program. (March 1980)

3. TASK B-1 - CORONA ABATEMENT

L. B. Browder - NRL-USRD

3.1. BACKGROUND

A significant percentage of transducer failures is due to voltage breakdown of insulating materials developing from corona erosion mechanisms. It is not practical to test the end item (transducer) to quantify the effects of corona erosion on transducer reliability and lifetime. Corona must be studied as a failure mechanism at the component or piece-part level to quantify the protection requirements and establish reliability factors. Transducer reliability may then be achieved by control of design parameters and construction processes.

3.2. OBJECTIVES

The objectives of this task are:

- To provide consultation in selecting materials useful in corona abatement for sonar transducers.
- To reduce corona and flashover damage by quantifying voltage breakdown levels with various design parameters that may be specified and controlled.
- To study the insulating properties and corona resistance of the piezoelectric ceramic material that is an essential part of sonar transducers.
- To identify and test various thin films and coatings with high dielectric strength to establish their usefulness at reducing corona.
- To determine the quality control factors to be considered for corona abatement materials and methods selected for use in transducers.
- To provide guidance for establishing general specifications for corona abatement and high-voltage design and construction.

3.3. PROGRESS

3.3.1. The PZT ceramic lifetime function for the continuous application of 60 Hz voltage was evaluated in dry and wet air and the electronegative gases sulfur hexafluoride (SF_6) and perfluoroethane (C_2F_6). The results indicate that although SF_6 is an adequate insulator gas for improving the electrical strength of sonar transducers, the relative improvement compared to dry air is much less than was expected from previous tests.

The lifetime function was evaluated by applying the drive voltage to circular discs of .635 cm (.25 in) thickness PZT ceramic polarized in the 3-3 mode. The test specimen was located in a 2000 ml glass test chamber with an associated gas handling system to allow control of the gas composition, pressure, and humidity. A new test specimen and gas fill is used for determining each datum point on the voltage/time curve. The lifetime function is progressively generated by obtaining datum points at voltage set levels proceeding downward from the maximum withstand voltage (short-term) strength of the test specimen. For these tests, the gas pressure was set at 101 kPa, the water vapor partial pressure content of the dry gases was less than 0.24 Torr or 1% R.H., and the ambient temperature was 25°C.

The voltage lifetime function for PZT ceramic in each of the insulating gases is shown in Fig. 3.1.

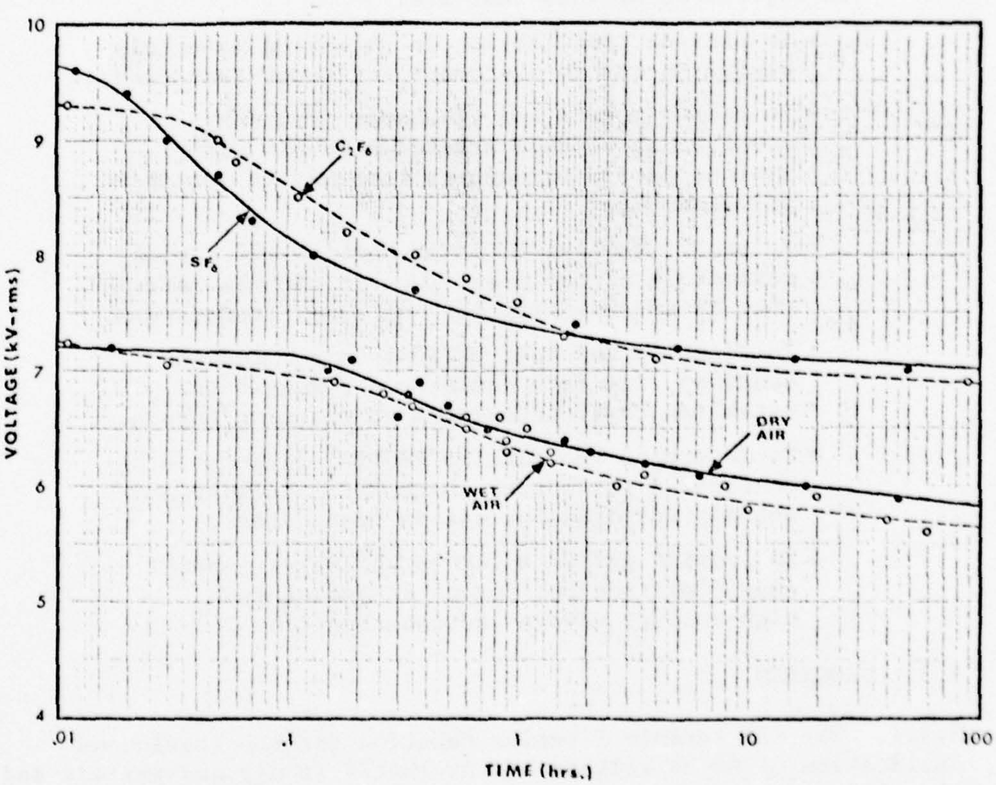


Fig. 3.1 - Voltage lifetime functions for 0.635-cm thickness PZT ceramic in various insulator gases.

The time axis shows the length of time to voltage breakdown at the different voltage levels. Each of the functions has three regions of interest: (1) the higher voltage area that is the maximum short-term withstand capability, (2) an intermediate area in which a time-dependent breakdown mechanism operates, and (3) a long-term area in which the ceramic can operate indefinitely without breakdown.

The main indications of the lifetime functions shown in Fig. 3.1 that apply to sonar transducer design are the following:

- The long-term voltage withstand capability of SF_6 and C_2F_6 gases compared to dry air is approximately 1.2 or 20% greater. This compares to earlier indications that the margin was 60-70% greater.
- In SF_6, the intermediate breakdown mechanism operates more rapidly by a time factor of 2 than in C_2F_6. In dry air, however, the intermediate mechanism operates more slowly than with either of these gases.
- Wet air has a long-term voltage withstand capability of about 4% less than dry air, thus a sonar transducer containing dry air should last 2-5 times longer than one with wet air if operated with the same voltage drive.

Factors of primary concern in this investigation of the PZT ceramic voltage lifetime function are those that affect the long-term voltage withstand capability. This includes such items as gas composition and pressure, ambient temperature, surface coatings or treatments, and electrode configurations.

3.3.2. During the course of obtaining these voltage lifetime functions, it was discovered that there is a parasitic current flow to the test specimens that is not related to either corona or the usual capacitive component. The progress of the test leading up to the arc breakdown could be monitored and predicted by watching certain small irregularities on the corona detector indicator. These irregularities build up to a high level just before failure occurs. This was an indication of a current pulse at the peaks of the drive voltage, but having frequency components below the low cut-off of the corona detector. These current pulses appear to be different than corona because no light or glow is associated with the phenomena even though the current is at a relatively high level compared to corona.

The electrical current pulse at the peaks of the drive voltage has been indirectly observed using a current transformer with an amplifier and band-pass filter. This method is less than optimum because much of the current waveform is obscurred by the third and fifth harmonic frequency components of the 60 Hz fundamental. A better method that will be used is a current-balance technique that will separate the desired real-time current pulses from the common-mode components. This should yield information on the inception voltage level and changes in the current waveform leading to the ceramic failure point.

Tentative characteristics of this parasitic current-flow phenomena are as follows:

- The current pulse occurs roughly on the peaks of the drive voltage waveform, but the current maximum is slightly lagging the peak.
- This current flow is probably a surface phenomena because it behaves differently in the various insulator gases.
- The current pulse progressively increases in amplitude by a factor of approximately 3 as the ceramic proceeds to breakdown.
- The magnitude of the current pulse is sufficiently large to produce a power dissipation of 0.5 to 5 watts on the ceramic surface and may be localized to specific points on the surface so that "hot spots" occur.
- The current pulses are not of equal amplitude on the positive and negative halves of the driving voltage waveform, but are non-symmetrical so that the maximum current pulse occurs when the driving voltage and the ceramic polarity are in series aiding.
- The predominant frequency component introduced by the pulses on the current waveform is the sixth harmonic (360 Hz) of the driving voltage.
- There is a specific minimum driving voltage at which the current pulses have their inception, for instance with .635 cm (.25 in) thickness ceramic in dry air the beginning point is between 3 and 4 kV.

3.3.3. These new observations will broaden the scope of this investigation somewhat because the phenomena has been directly observed to proceed to electrical breakdown of PZT ceramic. The result could be a new diagnostic procedure that will give direct indication of safe operating voltages for sonar transducer elements without exposing the assembly to destructive voltage levels.

3.4. PLANS

3.4.1. Continue the study of the PZT ceramic lifetime function to evaluate changes due to gas pressure with SF_6 gas and due to the impurities carbon dioxide and methane in dry air.

3.4.2. Develop instrumentation and a test procedure that will give a direct real-time indication of the low-frequency parasitic current phenomena associated with high-voltage on the PZT ceramic.

3.4.3. Prepare a technical memorandum report on the voltage withstand lifetime function of PZT ceramic.

4. TASK C-1 - CABLES AND CONNECTORS

G. D. Hugus - NRL-USRD and
D. E. Glowe - Texas Research Institute, Inc.

4.1. BACKGROUND

The use of cables and connectors is an area of concern for long-term sonar reliability because of a history of failures. Deficiencies can be generally categorized in the four areas of: design of cables and terminations; specification and testing; handling; and repair and maintenance. Specific problems have been identified in a recent failure modes and effects analysis of cables and connectors prepared for NAVSEA by General Dynamics/Electric Boat. They conclude, that of all the problem areas, the loss of bond of the molded boot to the connector shell or to the cable sheath is the most probable cause of failure. Cable jacket puncture in handling, at installation or in service is considered to be the second most probable cause of failure. These are the two problem areas to be addressed here.

4.2. OBJECTIVES

The general objective of the task is to provide improved reliability in the cables, connectors, and related hardware for the outboard elements of sonar transducer systems. It is occasionally necessary to also consider portions of the system interior to the ship's hull because the same cables are often used for significant distances through compartments inside the ship before terminating at their ultimate electronic package destination.

Specific objectives for the FY79 task area as follows:

- Investigate the use of cable/connector boot clamps to determine reliability and failure modes.
- Investigate the strength of unshielded cable and the shielded cable to determine reliability and failure modes.

4.3. PROGRESS

4.3.1. Work to fulfill these objectives is being performed under contract N00173-79-C-0129 by Texas Research Institute, Inc. A task outline of this work was given in the STRIP Third Quarter Progress Report (NRL Memorandum Report 4009). The progress so far has been achieved mostly on Tasks 1 and 2 as follows:

- TASK 1: Develop Mission Profile and Test Plan

The purpose of Task 1 is to produce quantitative data about the environment and conditions which cables experience during storage, installation, ship operations and maintenance, to design a test plan to adequately simulate those experiences, and to obtain sufficient cable to evaluate the program. This task has been completed. The mission profiles generated from this task and Task 4 for connectors have been combined. They are divided into the following exposure categories for cables and connectors:

- Transportation and storage, environmental
- Installation and maintenance, environmental
- Installation and maintenance, mechanical, types DSS-2, DSS-3, DSS-4, and FSS-2 cable
- SSN service
- SSBN service
- Surface ship service

Tables 4.1, 4.2, 4.3, and 4.4 show the mission profiles for the transportation and storage and SSN, SSBN, and surface ship service categories.

- TASK 2: Comparative Testing of Cables

The test plan devised in Task 1 will be carried out with the testing of several cables commonly used in the fleet. They are:

SHIELDED	UNSHIELDED
DSS-2	DSU-2 (Two types)
DSS-3	DSU-3
DSS-4	Trident 2-Conductor
FSS-2	Butyl 2-Conductor
	DSU-2 with reinforcement

NO	EXPOSURE	EXPOSURE RANGE	OCCURANCE	DURATION (Time or Cycles) EXTREME	PER 1 YR.	CONTINUING LONG TERM	PER 1 YR.	COMPANION EXPOSURE
1	Temperature In Air	-30° to +70°C	Storage, Outside Uncovered	70°C, 5 Hr/Day x 360 Days	1800 Hrs			Humidity Ultraviolet Air Pollution
2				-30°C, 12 Hr/Day x 30 Days	360 Hrs			
3			Covered Storage			-6° to + 38°C	8640 Hrs	
4	Pressure In Air	12 to 100 kPa	Air Transportation	12 kPa 2 Flights x 8 Hrs	16 Hrs			Humidity Temperature Air Pollution
5			Storage			100 kPa	8640 Hrs	
6	Humidity	-30° to +38°C Dew Point	Storage	-30°C Dew Point 30 Days	720 Hrs			Temperature Ultraviolet Air Pollution
7				+38°C Dew Point 120 Days	2880 Hrs			
8						+10° to 32°C Dew Point,	8640 Hrs	
9	Ultraviolet Radiation	0-8300 $\mu w/cm^2$ @ 290 - 400nm	Storage Outside Uncovered	8300 $\mu w/cm^2$ 1.5 Hr/day for 270days	410 Hrs			Temperature Humidity Air Pollution
10						200 $\mu w/cm^2$ 12 Mo.	8640 Hrs	
11	Air Polution	0 -500 AQL[a]	Storage	500 AQL for 8 days[b]	192 Hr			Temperature Humidity Ultraviolet
						200 + 50 AQL for 270 Days	6480 Hrs	

a - AQL - Air Quality Level Defined By EPA
b - Based on Los Angeles Experience, 1975. Ozone is the major contaminant.

Table 4.1 - Mission Profile - Transportation and Storage Cables and Connectors

NO.	EXPOSURE	RANGE OF EXPOSURE	OCCURANCE	DURATION OF EXPOSURE (hrs or cycles) EXTREME	PER 1 YR.	CONTINUING LONG TERM	PER 1 YR.	COMPANION EXPOSURE
1	Temperature/ Air	-55° to +60°C	Dockside	+60°C, 1.5 hr/day-270days	405 hr			Humidity Pollution
2				-30°C 24 hr/ day - 30 days	720 hr			
3						+3° to +37°C for 270 days	6480 hr	
4			Arctic Surface	-55°C for 21 days	504 hr			
5	Temperature/ Sea Water	-2° to +32°C	At Sea	+32°C for 90 days	2160 hr			Pressure
6						-1° to 11°C for 90 days	2160 hr	
7	Thermal Cycling	$\Delta T \leq 48°C$	Dockside	$\Delta T = 48°C$	270 cycles			Humidity Pollution
8						$\Delta T \leq 28°C$	365 cycles	
9	Thermal shock	$\Delta T \leq 53°C$	Diving-Tropic	$\Delta T \leq 28°C$	30 cycles			
10			Diving-Arctic	$\Delta T \leq 53°C$	3 cycles			
11	Pressure/ Sea Water	100 to 4100 kPa	At Sea	4100 kPa day - 90 days	180 hr			Temperature Vibration
12						700 to 2100 kPa for 90 days	2160 hrs	
13	Pressure Cycling/Sea Water	100<P<4100 kPa	At Sea	100 to 4100kPa 2/day - 90days	180 cycles			
14						700 to 2100kPa 90days	180 cycles	
15	Humidity	-55° to +38°C Dew Point	Surface	38°C D.P. 24 hr/day - 270 days	6480 hr			Temperature Pollution
16						10° to 32°C D.P. - 270days	6480 hr	
17	Air Pollution	0-500 AQL[a]	Dockside	500 AQL 8 days[c]	192 hr			Temperature Humidity
18						200 ± 50 AQL 270 days	6480 hr	
19	Vibration	Per MIL-STD-167-1[b]	At Sea	Per MIL-STD - 167-1	1 series			Temperature Pressure
20	Explosive Shock	Per CIPS[b]		Per CIPS	1 series			Pressure
21	Tensile Stress, Static	Note d	All Service			Continuous Stress per Note d	8640 hr	

NOTES:

- a AQL = Air Quality Level as defined by EPA.
- b Vibration and explosive shock as defined by specification due to lack of service data.
- c Based on Los Angeles experience, 1975. Ozone is the major contaminant.
- d Static stress based on 10 meters of unsupported cable. DSS-2 = 6 kg, DSS-3 = 10 kg, DSS-4 = 12 kg, FSS-2 = 12 kg.

Table 4.2 - Hypothetical SSN Service Profile - Cables and Connectors

NO.	EXPOSURE	RANGE OF EXPOSURE	OCCURANCE	DURATION OF EXPOSURE (hrs or cycles): EXTREME	PER 1 YR.	CONTINUING LONG TERM	PER 1 YR.	COMPANION EXPOSURE
1	Temperature/ Air	-55° to +60°C	Dockside	+60°C, 1.5 hr/day-40days	60 hr			Humidity Pollution
2				-30°C 24 hr/ day - 20 days	480 hr			
3						+3° to 37°C for 60 days	1440 hr	
4			Arctic Surface	-55°C for 21 days	504 hr			
5	Temperature/ Sea Water	-2° to +32°C	At Sea	+32°C for 270 days	6570 hr			Pressure
6						1°C + 11°C ? for 270 days	6480 hr	
7	Thermal Cycling	$\Delta T \leq 48°C$	Dockside	$\Delta T = 48°C$	60 cycles			Humidity Pollution
8						$\Delta T \leq 28°C$	60 cycles	
9	Thermal shock	$\Delta T \leq 53°C$	Diving-Tropic	$\Delta T \leq 28°C$	300 cycles			
10			Diving-Arctic	$\Delta T \leq 53°C$	300 cycles			
11	Pressure/ Sea Water	100 to 4100 kPa	At Sea	4100 kPa day - 300 days	7200 hr			Temperature Vibration
12						700 to 2100kPa for 300 days	7200 hrs	
13	Pressure Cycling/Sea Water	100<P<4100 kPa	At Sea	100 to 4100kpa 2/day-300days	600 cycles			
14						700 to 2100kPa	600 cycles	
15	Humidity	-55° to +38°C Dew Point	Surface	38°C D.P. 24 hr/day - 60 days	1440 hr			Temperature Pollution
16						+10° to +32°C D.P. - 60days	1440 hr	
17	Air Pollution	0-500 AQL[a]	Dockside	500 AQL 8 days[c]	192 hr			Temperature Humidity
18						200 ± 50AQL - 60 days	1440 hr	
19	Vibration	Per MIL-STD-167-1[b]	At Sea	Per MIL-STD - 167-1	1 series			Temperature Pressure
20	Explosive Shock	Per CIPS[b]		Per CIPS	1 series			Pressure
21	Tensile Stress, Static	Note d	All Service			Continuous Stress per Note d	8640 hr	

NOTES:

a AQL = Air Quality Level as defined by EPA.
b Vibration and explosive shock as defined by specification due to lack of service data.
c Based on Los Angeles experience, 1975. Ozone is the major contaminant.
d Static stress based on 10 meters of unsupported cable. DSS-2 = 6 Kg, DSS-3 = 10 Kg, DSS-4 = 12 Kg, FSS-2 = 12 Kg.

Table 4.3 - Hypothetical SSBN Service Profile - Cables and Connectors

NO.	EXPOSURE	RANGE OF EXPOSURE	OCCURANCE	DURATION OF EXPOSURE (hrs or cycles) EXTREME	PER 1 YR.	CONTINUING LONG TERM	PER 1 YR.	COMPANION EXPOSURE
1	Temperature/ Air	0° to +38°C	Dockside	0° C 180 days	4320 hr			Humidity Pollution
2				+38°C 360 days	8640 hr			
3						+3° to +37°C for 360 days	8640 hr	
4	Temperature/ Sea Water	-2° to 32°C	Artic	-2° C for 180 days	4320 hr			
5			Tropical	+32°C for 360 days	8640 hr			Pressure
6						0° to +30°C for 360 days	8640 hr	
7	Pressure/ Sea Water	100 to 250 kPa	Service	250 kPa day - 360 days	8640 hr			Temperature Vibration
8						100 to 250 kPa for 360 days	8640 hrs	
9	Humidity	0° to +38°C Dew Point	Service	38°C D.P. 360 days	8640 hr			Temperature Pollution
10						10° to +32°C D.P. - 360days	8640 hr	
11	Air Pollution	0-500 AQL[a]	Dockside	500 AQL 8 days[c]	192 hr			Temperature Humidity
12						200 ± 50 AQL 360 days	8640 hr	
13	Vibration	Per MIL-STD-167-1[b]	At Sea	Per MIL-STD - 167-1	1 series			Temperature Pressure
14	Explosive Shock	Per CIPS[b]	At Sea	Per CIPS	1 series			Pressure
15	Tensile Stress, Static	Note d	All Service			Continuous Stress per Note d	8640 hr	

NOTES:

a AQL - Air Quality Level as defined by EPA.

b Vibration and explosive shock as defined by specification due to lack of service data.

c Based on Los Angeles experience, 1975. Ozone is the major contaminant.

d Static stress based on 10 meters of unsupported cable. DSS-2 = 6 Kg, DSS-3 = 10 Kg, DSS-4 = 12 Kg, FSS-2 = 12 Kg.

Table 4.4 - Hypothetical Surface Ship Service Profile - Cables and Connectors

The tests being conducted are summarized in Table 4.5. All cable tensile breaking strength tests have been completed on cables and components. The failure mode for all cables was breakage of a conductor. Electrical measurements of insulation resistance and conductivity verified this mode. All cables have been tested for internal abrasion. Test samples were cycled back and forth underwater over an octagonal mandrel. Electrical measurements of continuity, insulation resistance between conductors, conductors to shield, and shield to water showed the failure mode to be a broken (open) conductor. The breaking bend tests are not complete. Crush resistance tests are complete. Here cable samples were placed between 5 cm long metal plates and the force required for failure was measured. The failure mode was conductor to conductor shorting for all but one cable type where a broken (open) conductor occurred. The compression set in a hull penetrator test is partially complete with single samples of DSS-3 and DSU-3 tested. Preliminary data show incremental movement of the unshielded cable through the hull penetrator during each pressure cycle.

TEST NO.	TEST	MISSION PROFILE REF.		MEASUREMENTS OBSERVATIONS	OBJECTIVE
1	Tensile Breaking Strength	Installation & Maintenance	Cable & Components All Samples	Ultimate Strength, Elongation, Order of Conductor (Component) Break, Continuity	Ultimate Strength, Resistance to Maintenance & Installation Abuse
2	Internal Abrasion	Installation & Maintenance	Cables All Samples	Stress, Cycles, Elongation, Continuity, Resistance Breakdown (Megohm)	Fatigue Strength, Insulation Degradation Due to Internal Conductor Break
3	Breaking Bend Strength	Installation & Maintenance	Cables All Samples	Ultimate Strength, Elongation, Mode of Electrical Failure (Open or Short)	Mode of Electrical Failure Ultimate Strength Due to Tension over a Round Surface
4	Crush Resistance	Installation & Maintenance	Cables All Samples	Force to Failure Mode of Failure (Open or Short)	Resistance to Crushing Force, Mode of Failure
5	Compression Set In Penetrator	Service	Cables (DSS-3, DSU-3)	Electrical (Open or Short) Physical Dimensions, Grommet Compression, Pressure to Leak or Cable Movement, Permanent Set in Cables	Effect of Stuffing Tube on Physical/ Electrical Characteristics
6	Creep in Static Tension	Installation & Maintenance, Service	Cables	Stress, Time, Elongation Continuity of Conductors	Effect of Unsupported Vertical Cable

Table 4.5 - Test Plan Summary - Cables

The candidate cable/connector boot clamps chosen for evaluation include three types, two of which are retrofittable.

Work on all tasks is in progress and on schedule.

4.3.2. One result of the work done in this task area of STRIP in FY78 was the recommendation to establish administrative and logistic control of cables and connectors at the NAVSEA level, just as had been done in the past with the transducers themselves. One step in this direction has occurred with the establishment of a *Cables and Connectors Working Group* headed by C.A. Clark of NAVSEA 63XT1. Another meeting was held on 25 and 26 September 1979. The objectives of the last two meetings were to determine the cause of failures and improve reliability in two cable connector areas: the MIL-C-24231 cable connector and the present methods of making in-line splices of MIL-C-915 cable. Research and development performed under this STRIP task has direct application to these problems. Minutes of the meetings can be obtained from C.A. Clark, NAVSEA 63XT1.

4.4. PLANS

The work will continue on the contracted project with all testing and preliminary data analysis complete by the end of the next quarter. Other *Cables and Connectors Work Group* meetings will be held after presently planned work has produced results requiring group attention and action.

5. TASK D-1 - MATERIALS EVALUATION

C. LeBlanc - NUSC and
C. M. Thompson - NRL-USRD

5.1. BACKGROUND

Pressure release materials are used to mechanically and/or acoustically isolate some components of sonar transducers to improve overall acoustic performance. Normally the pressure release materials must operate effectively under bias stress anywhere from 50 psi to 3 kpsi over a discrete temperature range, e.g., 5°C to 40°C. To predict performance it is essential to know the properties of the materials under the imposed constraints. Previous measurement methods for determining the properties of some pressure release materials, such as Sonite (an asbestos - glass fiber composite), onion-skin paper, syntactic foams, Hytrel (a thermoplastic polyester elastomer), etc., have given relative results with a hydraulic press or bulk effects with an impedance tube. There is a strong need to correlate existing measurement data and to establish a standard measurement system to be used by the Navy for incorporation into specifications and/or acceptance tests on pressure release materials.

An additional problem is that pressure release materials absorb the transducer fill-fluids. This process increases the acoustic impedance of the pressure release material and thus reduces the effectiveness of its acoustic insulation. Degradations of from 3 dB in 3 years to 6 dB in 10 years have been reported in transducers in the field, and attributed to changes in the pressure-release material.

There are thus two phases to this task: the material characterization phase and the fluid absorption phase.

5.2. OBJECTIVES

The objectives of this task are:

- To initiate and evaluate a standard dynamic measurement system to determing the properties of pressure release materials over the ranges of stress from 50 psi to 3 kpsi and at temperature from 5 to 40°C.
- To measure and evaluate candidate pressure release materials, such as Sonite, onion-skin, corprene, etc.
- To quantify the changes in acoustic properties of cork-rubber composites as they absorb transducer fill-fluids.

- To test a transducer element for changes in sensitivity as a function of castor oil content of its pressure release material.
- To develop a method that will predict changes in the acoustic properties of cork-rubber composites with time (and in turn predict changes in transducer directivity and sensitivity).
- To identify the specific problems with DC-100 which may eventually lead to its replacement with a more suitable material.

5.3. PROGRESS

5.3.1. The dynamic measurement system for the material characterization phase was described in the previous quarterly progress report, and will not be repeated here.

Preliminary static measurements were attempted to define a basis for the dynamic measurement data to follow. Static stress was applied to the samples with a nut and stress rod assembly and the measured strain in the rod. Displacement of the samples was monitored with a fiber optic probe.

Initial measurements on paraffin samples showed extensive creep of the material at low stress levels (< 100 psi) and gave indications of erroneous strain measurements due to bending of the stress rod during the nut torquing operation. The rod was rewired with two balanced strain gages to eliminate bending effects. The double gage assembly was then calibrated for axial loading by applying a known force to the rod with a Carver press.

After the adjustments, additional static measurements on other paraffin samples at low stress level (≈ 20 psi) yielded values of Young's modulus of 2100 MPa (300 kpsi) or 30% higher than published values. The measured value is reasonable since paraffin samples are quite variable. Thus, the static measurement scheme may be considered to be working satisfactorily. However, paraffin, because of the creep problem at low stress level, has been abandoned as a control material to determine lateral constraint effects induced by friction between the sample and the loading mass surfaces.

Hytrel, a thermoplastic polyester elastomer, was selected as the alternate material for lateral constraint studies. Two static runs on a virgin (i.e., unstressed) 55 durometer sample, 3.5 inches outside diameter by 1.0 inch thick, gave values of 275 MPa (40 kpsi) (1st cycle) and 345 MPa (50 kpsi) (2nd cycle) for

Young's modulus to a stress level of 1 kpsi. (Creep was not noticeable at this stress level in the sample.) The values listed above are roughly twice the values quoted by Dupont for injection molded test specimens at the same stress level. However, the values listed above are more in line with values measured on similar material at NSRDC. The higher values might also be indicative of lateral constraint effects and this aspect of the overall measurement scheme is being addressed.

The contract with Raytheon for math modeling of the dynamic measurement system was not finalized until July due to time delay in contract processing (roughly 6 months). The model should predict complex sound velocities of pressure release materials over the frequency range from low frequency ($\approx$ 100 Hz) to the first major resonance of the driver assembly ($\approx$ 3.5 kHz). Higher frequency dependence of the materials can be handled with smaller driver units.

Thus, all of the math modeling will not be completed this year, but the effort should be completed by the middle of the next fiscal year (FY80).

5.3.2. Impedance tube testing to determine the reflection coefficient, speed of sound and attenuation for the cork-rubber composites has been completed. The measurement method is based on the analogy between an electrical and an acoustical transmission line. Plane wave propagation is assumed, and is attained in practice by using a rigid-walled tube with a diameter that is very much smaller than the wavelength of sound in the water and in the test material.

The input impedance of a test sample terminated in an infinite impedance can be expressed as

$$Z_i = Z_o \coth \gamma d, \tag{5.1}$$

where Z_i is the input impedance of the sample, Z_o is the characteristic impedance of the sample, $\gamma = \alpha + jk = \alpha + j\omega/c$ is the complex propagation constant of the sample, α is the attenuation constant, $\omega = 2\pi f$ is the angular frequency, c is the speed of sound, and d is the sample length.

The complex reflection coefficient can be related to the input impedance by the familiar equation

$$R = (Z_i - \rho_T c_T)/(Z_i + \rho_T c_T) , \tag{5.2}$$

where R is the complex reflection coefficient and $\rho_T c_T$ is the characteristic impedance of the water in the tube. Then, by substituting the value of Z_i from Eq. (5.1) into Eq. (5.2) the reflection coefficient can be expressed as a function of the propagation constant of the material and the characteristic impedances of the material and of water.

One further relation is needed to express the reflection coefficient in terms of the propagation constant and of other easily measured quantities:

$$Z_o = j\rho\omega/(\alpha + jk), \qquad (5.3)$$

where ρ is the density of the sample. Thus, the measured quantities are sample density and length, frequency, characteristic impedance of the water in the tube, and complex reflection coefficient. The calculated quantities are the attenuation constant and the speed of sound.

The samples for the impedance tube tests were cut into 5-cm diameter disks. The length of the samples is limited by theory to less than one-tenth the wavelength of sound in the material; therefore, sample length was approximately 0.317 cm (1/8 in). The oil-soaked disks had been exposed to castor oil at 75°C for 12 months prior to impedance tube testing.

The test results for the five cork-rubber materials being investigated are presented in Figs. 5.1 through 5.5. The graphs show the speed of sound and attenuation versus hydrostatic pressures up to 16 MPa. The curves represent average values over a range of frequencies from 3 kHz to 10 kHz.

The graphs show that in unsoaked samples the sound speed curves are very similar, while in the castor oil soaked samples, the speed of sound varies significantly. Table 5.1 shows that there is an approximate relationship between the amount of castor oil in the materials and the percentage increase in the speed of sound.

A similar, but less exact, correspondence can be deduced from the attenuation curves; that is, the lower the percentage castor oil absorbed, the smaller the decrease in attenuation.

CORK-RUBBER MATERIAL	% INCREASE IN WEIGHT	% INCREASE IN SOUND SPEED
DC-116	68	210
DC-100	65	198
NC-710	50	123
NC-775	13	62
LC-800	9	25

Table 5.1 - Percentage increase in weight and sound speed (at 0 MPa pressure) for 5 cork-rubber composites exposed to castor oil at 73°C.

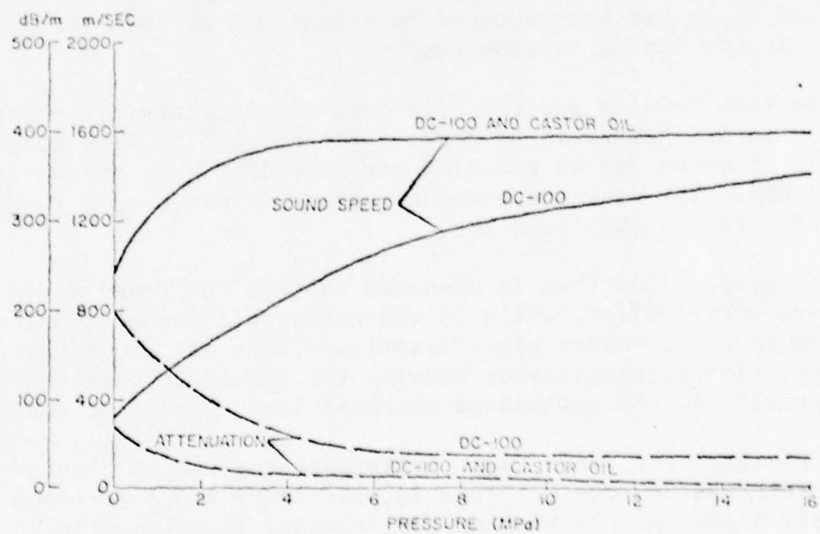


Fig. 5.1 - Acoustic Properties of Soaked and Unsoaked DC-100 Neoprene-Cork Composite

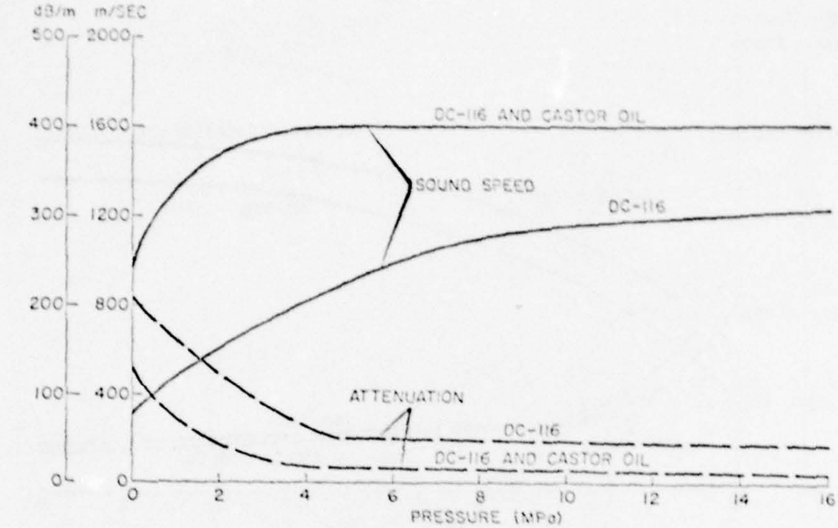


Fig. 5.2 - Acoustic Properties of Soaked and Unsoaked DC-116 Neoprene-Cork Composite

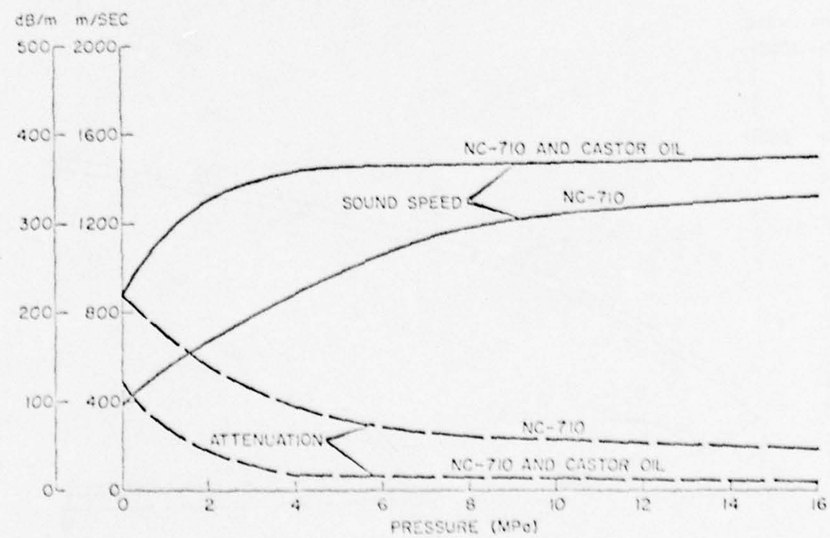


Fig. 5.3 - Acoustic Properties of Soaked and Unsoaked NC-710 Nitrile Rubber-Cork Composite

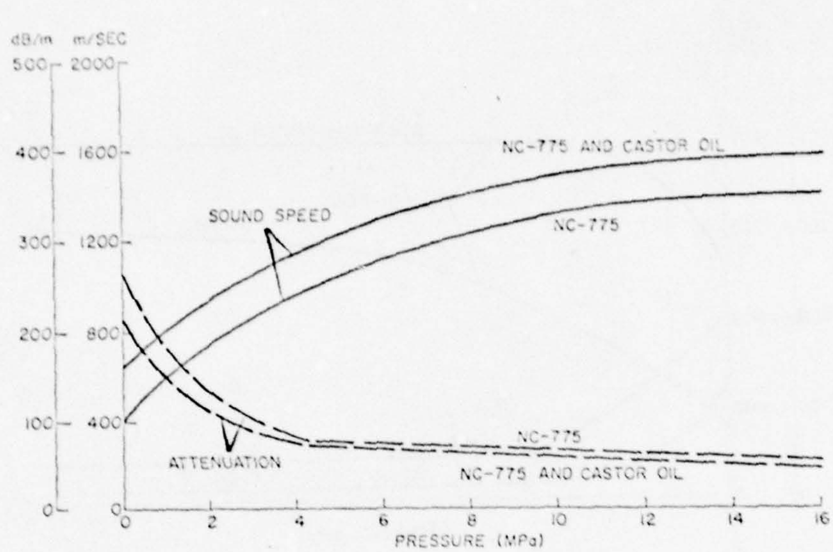


Fig. 5.4 - Acoustic Properties of Soaked and Unsoaked NC-775 Nitrile Rubber-Cork Composite

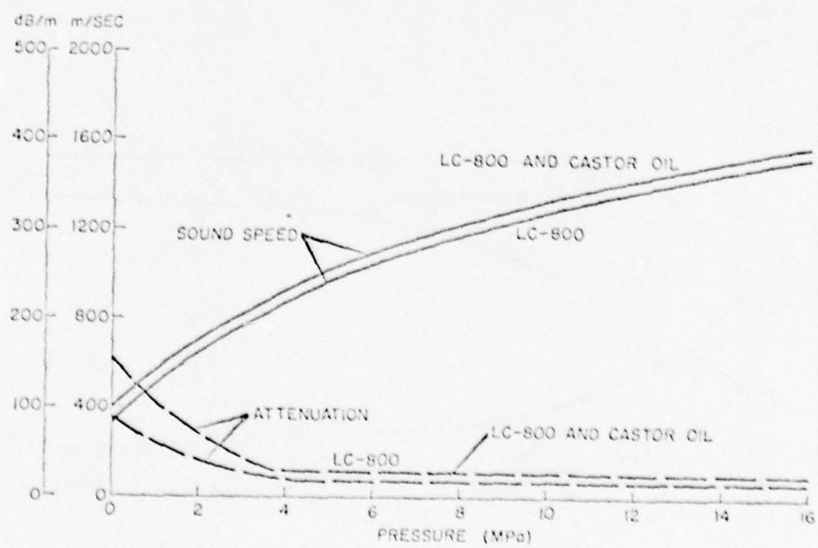


Fig. 5.5 - Acoustic Properties of Soaked and Unsoaked LC-800 Silicone Rubber-Cork Composite

5.4. PLANS

- Changes in sensitivity of a transducer element as a function of castor oil content of its pressure release material will be determined with a G19 calibrator.
- A final report will be written which incorporates details about the various oil soaking and impedance tube testing along with recommendations about either a better pressure release material, a method to minimize changes in existing materials or a way to compensate for changes.
- Measure static and dynamic properties of pressure release materials at ambient temperature.
- Investigate frequency dependence of pressure release materials.

6. TASK E-1 - STANDARDIZED TEST PROCEDURES

J. Wong and D. Carson - NOSC

6.1. BACKGROUND

It is at present not possible to subject a transducer specimen to a series of environmental stresses over a short time period and prove, if it passes certain operating parameter tests, that the specimen is a reliable transducer with a certain minimum expected life in fleet use. Of course, if we could simply use a set of transducers for the desired fleet life, we could check the failure rates against acceptable replacement or repair rates. But the approach here is to accelerate the environmental stress actions, and thereby subject the transducer specimen to seven years of life cycle stresses in a few weeks or months.

6.2. OBJECTIVES

The objective of this task is to develop a set of standardized procedures to accelerate the aging of transducers based upon environmental stress requirements.

6.3. PROGRESS

6.3.1. TR-316 Transducers

The failure modes in the TR-316 transducers that have been revealed by Composite Unit Accelerated Life Test (CUALT) procedures have been documented in previous STRIP quarterly reports. During this quarter, piece part testing has been performed to identify the exact failures of the components and to determine the correlation of these failures to those of the composite unit.

The failure of the Ametek/Straza TR-316 transducer wide beam sections due to current runaway at high power drive resulted in the rejection of the initial first article transducers. This prompted an investigation to determine the specific cause of the current-runaway problem. Evidence from high-drive tests, signs of overheating in disassembled failed units and individual resonator in-air impedance versus temperature tests narrows down to two probable problem areas:

- Improper assembly technique of the transducer resonators caused rapid deterioration in the resonator impedance with increasing temperature.
- Poor heat transfer from the resonator ceramic to the water medium which in turn intensified the first problem indicated above.

These two problems were partly described in the last quarter progress report. Additional tests were completed during this present quarter.

The in-air impedance versus temperature measurements of individual resonators provided the insight necessary to understand and solve the current-runaway problem. In order to examine enough cases to be definitive in a short time period, it was necessary to automate the in-air impedance versus temperature measurement procedure for the resonators. This automation was accomplished, including automatic data graphing. In a very few minutes, a resonator incorporating a given design feature could be experimentally evaluated. Various resonators were tested; resonators from units that failed the high-drive tests; resonators from units which passed (in the cold ocean water) the 171 hours high-drive tests; resonators with no ceramic adhesive, various degrees of prestress and with production and reduced-diameter stress rods; resonators with properly constructed Epon 8 adhesive joints, the production stress rod but with extra high stress; and resonators using Epon 914 (high temperature) adhesive instead of Epon 8. It was decided later not to use the Epon 914 for production transducers because the high curing temperature of 204°C could cause deterioration of ceramic electromechanical properties.

Figures 6.1a and 6.1b are the in-air impedance magnitude and phase angle, respectively, of a representative resonator that failed the high-drive test. Note that even at the temperature of 66°C (150°F) the dB spread in the impedance magnitude between the resonance and antiresonance points is seriously reduced, indicating increasing losses in the stack. As the temperature is increased to 121°C (250°F), well below the temperature for which the piezoelectric material normally encounters temperature problems, the normal resonator resonance has disappeared and indications of extreme losses have become evident. Straza indicated that these early production resonators had a prestress of only 2.8 N-m (25 in-lbs) torque for the Epon 8 adhesive cure and a relative low final assembly stress of 5.6 N-m (50 in-lbs) torque. In contrast, Figs. 6.2a and 6.2b show the in-air impedance (magnitude and phase) of a Straza properly constructed resonator. This resonator also used Epon 8 adhesive as in the production resonators, but with a much higher prestress of 11.3 N-m (100 in-lbs) torque so that the adhesive joints are more uniform and thinner. The final stress for this resonator was set to approximately 31 MPa (3500 psi) at NOSC. Note that the in-air impedance is still quite satisfactory up to a temperature of at least 100°C (212°F). It was reasoned that the previous loss and probably erratic prestress applied by Straza had resulted in corresponding erratic adhesive joints of varying thickness. Even if the previously selected lower prestress used both for curing and final assembly had been achieved, it was speculated that the adhesive joints might have been excessively thick.

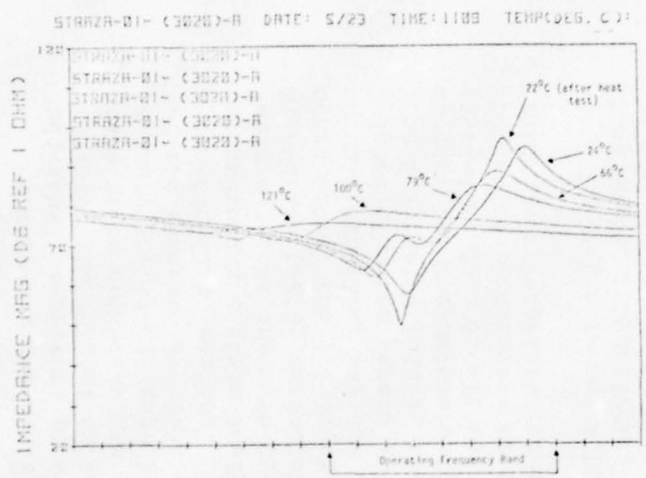


Figure 6.1a. Magnitude of In-Air Impedance Vs. Temperature for a "Bad Resonator"

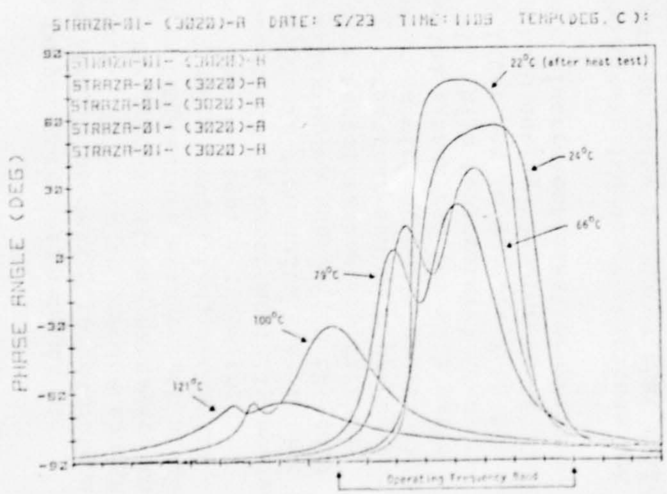


Figure 6.1b. Phase Angle of In-Air Impedance Vs. Temperature for a "Bad Resonator"

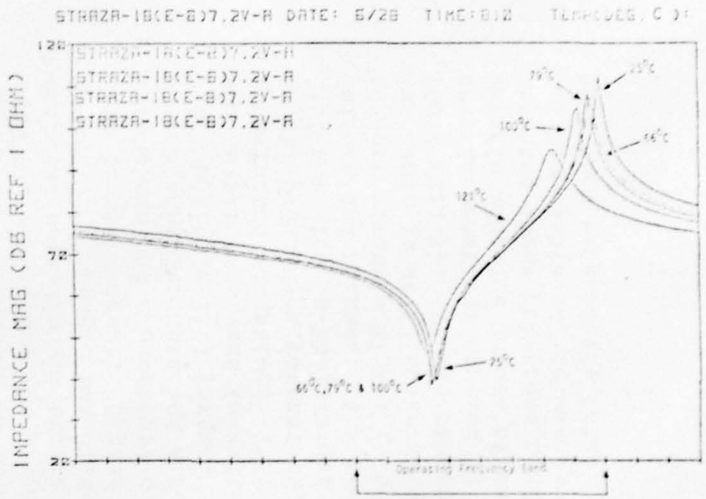


Figure 6.2a. Magnitude of In-Air Impedance Vs. Temperature with New Epon 8 Adhesive Joints and High Prestress

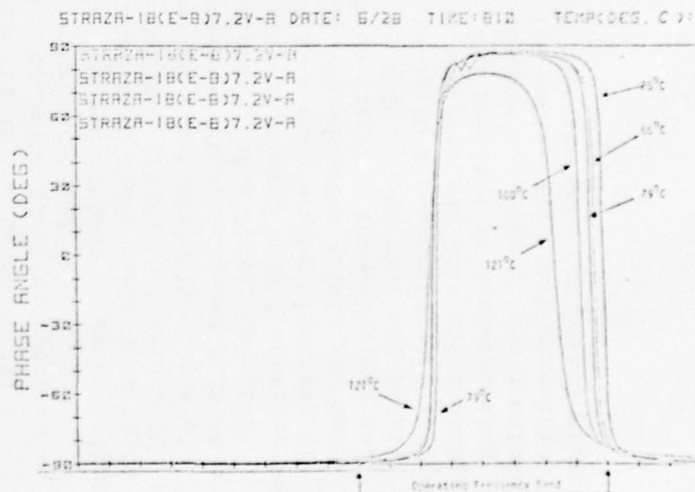


Figure 6.2b. Phase Angle of In-Air Impedance Vs. Temperature with New Epon 8 Adhesive Joints and High Prestress

6.3.1.3. To resolve the heat transfer problem it was necessary to measure the actual temperature attained in the wide beam sections of the composite TR-316 transducer under high drive level conditions. These stabilization temperatures for the resonators in the composite transducer were required not only for the old resonators but for resonators incorporating the improved Epon 8 adhesive joint construction technique with higher prestress. Also, it was decided to investigate a design which replaced the poor thermal-conducting micarta resonator retainer blocks with a NOSC fabricated aluminum resonator retainer block. This design puts the filler fluid in contact with the good thermal-conducting aluminum block, which is in turn in contact with the outside steel case interfacing with the water.

A number of combinations of transducers were tested to determine the temperature at which stability occurred. Temperature monitoring was accomplished by bonding a thermistor to the nodal ring of the center resonator in the wide beam sections. A single-frequency (lowest operating frequency) 126 V rms drive as well as a frequency-sweep drive were performed on the combination of most interest, namely, the units with the micarta block and an anodized aluminum block using the new resonator assembly technique and Epon 8. The frequency-sweep used as a continuous 2-seconds sweep up and 2-seconds sweep down across the operating frequency band at 120-130 rms. For the new Epon 8 resonator composite TR-316 configurations, the same set of resonators was used in all experiments (i.e., both in the micarta and aluminum blocks). Table 6.1 summarizes the steady-state stabilization temperatures for some of the more interesting experimental design configurations performed. These are the temperatures which were finally reached during high drives of the TR-316 experimental wide beam sections. The frequency-sweep drive test for the aluminum block will not be performed until FY80. Anticipated values were inserted in Table 6.1 based on the single-frequency drive tests.

TRANSDUCER SET	MICARTA BLOCK		ALUMINUM BLOCK		WATER TEMPERATURE
	SINGLE FREQUENCY	FREQUENCY SWEEP	SINGLE FREQUENCY	FREQUENCY SWEEP	
Old Epon 8 Resonators	Current runaway (>140°C)	*	*	*	22°C
New Epon 8 Resonators, adhesive cured using a higher prestress	85°C	85°C	65°C	65°C	22°C
New Epon 8 Resonators, adhesive cured using a higher prestress	*	92°C	*	** 72°C	32.2°C

* Not to be accomplished
** Tests were not performed, value indicated is an anticipated value

Table 6.1 - Resonator Stabilization Temperatures in the TR-316 Experimental Wide Beam Sections

Conclusions from the results of the individual resonator in-air impedance versus temperature and the resonator stabilization temperature tests are summarized.

- Low prestress on the ceramic stack during adhesive cure can result in excessively thick adhesive joints with high losses and accompanying increases in resonator temperature.
- Inadequate final assembly stress possibly could relieve the stress on the ceramic due to the difference in the coefficients of expansion of the stress rod and ceramic, thereby causing more losses and lowering of the resonance frequencies with increasing temperature.
- The torque wrench method used by Straza to apply stress on the ceramic is a questionable assembly procedure. It is known from experience that this method is notoriously inaccurate (for example, the ceramic stack might not be stressed at all if the nut seized upon the thread of the stress rod).
- There are no significant differences in temperature rise measured in the wide beam section between single-frequency and sweep-frequency drives.
- There is about a 20°C (36°F) temperature differential between the micarta and aluminum retainer block configurations (this gives a decided advantage to the aluminum block composite TR-316 with regard to the reduction of both temperature and the tendency for current runaway).
- An increase of 10°C in water ambient from 22°C to 32°C results in a corresponding increase of 7°C in maximum temperature of the composite TR-316.

As a result of extensive analysis and testing accomplished by NOSC, Ametek/Straza undertook a program of modification to improve and verify system performance. A summary of the changes is listed.

- The transducer housing has been modified to incorporate two (2) fill ports for each cavity section of the projector (PD up, PD down, and narrow beam).

- The oil-fill procedure has been modified to incorporate the principle of circulating warm, evacuated oil.
- The sylgard has been removed and the fill-fluid slot in the tail washer enlarged to provide improved oil filling within each resonator cavity (i.e., between the piezoelectric stack and the stress rod).
- A revised resonator-prestress precedure including the use of a digital multimeter to measure the charge has been incorporated to measure the prestress in lieu of the torque method.
- The resonator-assembly procedure was modified to provide a high stress on the stack while the cement cured. This produced an improved Epon 8 cement joint with lower losses, thereby solving the current-runaway problem.
- An anodized aluminum resonator retainer block has been fabricated and tested to improve the thermal dissipation and thus provide a safety factor with regard to the current-runaway problem. This aluminum resonator retainer block will replace the micarta resonator retainer block in the short sections (PD up and PD down sections). The micarta block will still be permitted in the long section (narrow beam sections).
- A revised tuning procedure has been incorporated whereby the reactive component is maintained inductive over the lower 5/8 of the operating band. Also, the improved performance of the new elements permitted a decrease in the transformer turns ratio while still meeting the source-per-volt requirement at or near +156 dB re 1 μPa @ 1 meter, thus providing an impedance greater than 100 ohms.

6.3.2. DT-605 Transducers

The two Hazeltine Corporation prototype DT-605 (S/N A1 and A5) transducers have completed the first-year-equivalent of operational stress conditions and are in the process of the acoustic performance check as required by the CUALT procedure. Testing was completed on one of the units in September 1979. However, time did not permit an in-depth evaluation of the results before the end of FY79. A cursory inspection of the TRANSDEC data for the first unit did not reveal any substantial changes in performance. Therefore, it does not appear there will be any holdup in completing the testing of the second unit.

6.3.3. A report entitled "Development of Composite-Unit Accelerated Life Testing (CUALT) Methods for Sonar Transducers, Part 1" is expected to be published by the end of November 1979.

6.4. PLANS

6.4.1 Initiate the second year of accelerated life test on the two DT-605 hydrophones.

6.4.2. Initiate the second year of accelerated life test on the TR-316 projectors when revised projectors from Ametek/Straza are received.

6.4.3. Start development of CUALT procedure for the SQS-56 transducers.

7. TASK F-1 - NOISE AND VIBRATION

C. I. Bohman - NOSC

7.1. BACKGROUND

As submarine platforms become quieter and sonar systems become more sensitive, problems associated with transducer self-generated noise become more acute. The very real problem of transducer-produced noise has already been highlighted. Transducer self-noise can block out that transducer's operation as well as radiate out into the medium. Radiated noise can also interfere with other acoustic systems of a ship or submarine. Because of those problems, all new or improved transducers should be scrutinized for noise sources. At present there are no fully accepted methods for correlating the radiated noise from an installed transducer with the results of a laboratory test for noise. In addition, it is difficult to distinguish transducer noise from extraneous noise when transducers are tested in pressure tanks.

7.2. OBJECTIVES

The objectives of this task are to:

- Review and evaluate existing transducer self-noise criteria.
- Isolate and analyze sources of self-generated noise in transducers.
- Develop analytical criteria and test methods for evaluating transducer-radiated self-noise.
- Apply radiated self-noise criteria and test methods to sonar transducer standards.
- Develop test methods to discriminate between transducer self-noise and extraneous noise during acceptance tests in pressure tanks.

7.3. PROGRESS

7.3.1. Reports

Technical Report TR 397, entitled "Development and Application of a Transducer Radiated Self-Noise Criterion Based on Optimal Detection Theory," has been written and advanced copies sent to NRL. Complete distribution of this report will be during October 1979. This report contains many of the results of the work performed under Task F-1, Noise and Vibration, STRIP, during FY78 and FY79. The report describing the TR-215 tests, entitled "Results of Radiated Self-Noise Measurements of TR-215 Transducer," (TN 647) will be published during October 1979.

7.3.2. Extraneous Noise Tests

In the STRIP Third Quarter Report (FY79) attention was directed to the problem of discriminating between transducer pressure induced noise and noise generated by the pressurization system during acceptance tests. The detection and elimination of extraneous system noise is essential to proper production testing. A simple solution to this problem would be to develop a pressurization system that is totally "quiet". However, until this is achieved methods of analyzing and discriminating system noise from transducer noise need to be developed.

A software program has been written and is currently being "debugged" which will analyze the transducer self-noise impulses in terms of peak pressure, total energy, energy spectral density, and time duration, and also compare the results of each. The purpose for this analysis is to evaluate the effectiveness of each type of measurement when used in conjunction with pressure tank tests. In addition, time and amplitude comparisons will be made to develop a testing technique which will eliminate extraneous noise impulses from transducer self-noise tests.

7.3.3. Pressure Release Materials Tests

The pressure release material samples supplied by NUSC have each been pressure cycled twice from 0-600 psig while monitoring the radiated self-noise. The test setup is illustrated in Fig. 7.1. Care was taken to isolate the pressure tank from pumping noise and structural vibration by having the pressure tank mounted on a large block of granite which was suspended on partially inflated inner tubes, and by connecting the hand pump to the tank via 20 feet of flexible pressure tubing as illustrated in Fig. 7.2. The radiated self-noise of each sample was analyzed over selected pressure ranges and plotted as a function of frequency as shown in Fig. 7.3. These spectrum levels will be compared with the minimum detectable source level as developed in the report TR 397, and an informal summary report will be written during October 1979.

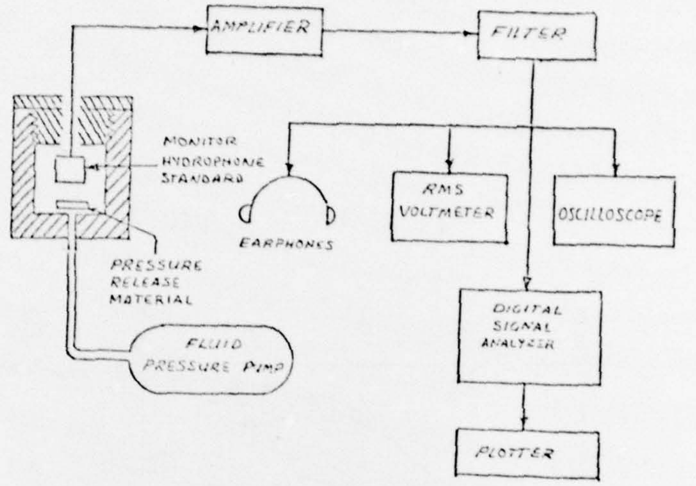


Fig. 7.1 - Pressure Release Material
Radiated Self-Noise Instrumentation Setup

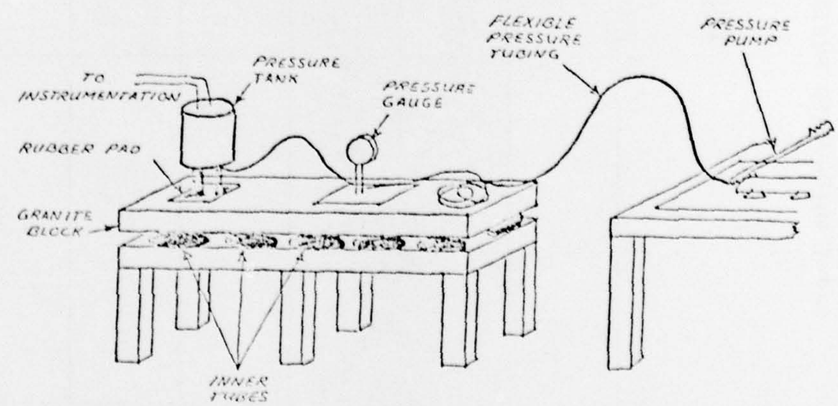


Fig. 7.2 - Pressurization System Setup

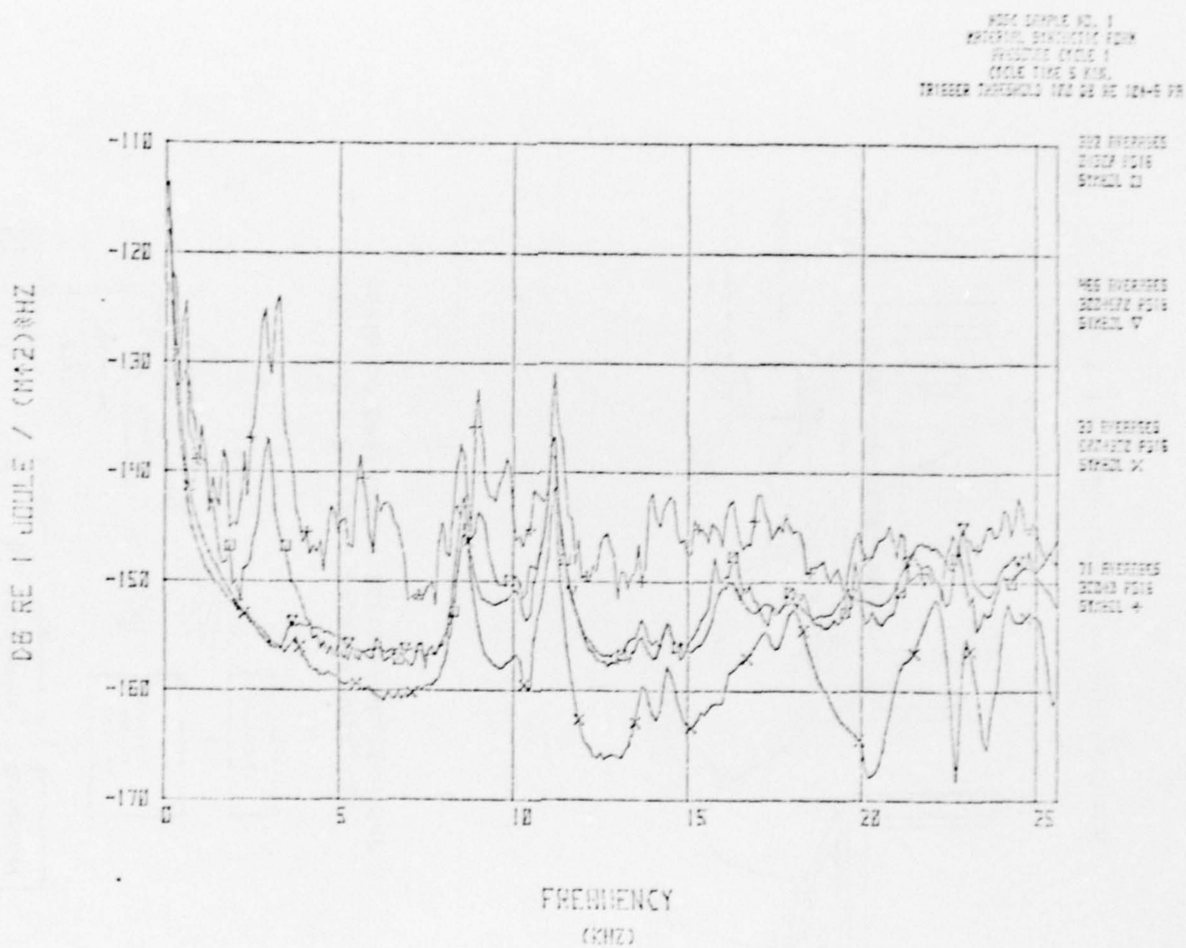


Fig. 7.3 - Pressure Release Materials Self-Noise Tests

7.3.5. Free-Field Measurements Test

Transducer self-noise free-field tests were conducted at Lake Pend Oreille during the last week of August. The main objective of free-field tests is to obtain recordings of different transducers' pressure induced self-noise in a free field to compare and correlate with recordings of the same noise obtained from pressure cycling in tanks. The results obtained from these tests would assist in projecting transducer radiated noise as measured in a pressure tank to an equivalent noise level that would be expected when measured in a free field.

The objectives of this first test were threefold, *First*, a specific method of obtaining free-field measurements of transducer self-noise, namely that of changing the pressure by lowering and raising the transducer in a large body of water while monitoring the self-noise, was to be investigated. *Second*, two "noisy" transducers were to be tested and the self-noise recorded. *Third*, the advantages and disadvantages of using Lake Pend Oreille as a site for these particular tests was to be investigated. In addition to the three objectives listed, a special transducer, modified by NRL to force the transducer to produce noise on command, was to be tested and calibrated.

On the first day of testing, shipping damages to the tow body prevented it from being used until repairs were made. The tow body was necessary for the tests to carry the transducers and monitor hydrophones while raising and lowering in the water. While repairs were being made, the special transducer was tested.

On the second day of testing, the tow body with the transducers and monitor hydrophones was placed in the water. While raising and lowering the transducers to 250 feet the bearings on the winch system, designed and built by a contractor, began to heat up. After being oiled and allowed to cool, the bearings again heated up. At this time it was decided that the special winch system should not be used.

On the third day the tow body was attached to the barge's winch system and placed in the water. Two pressure cycles were recorded to 600 feet at an average cycle time of one hour each. Although the tests did not proceed as planned, all three objectives were met. Two hours of good recordings of the transducer self-noise have been obtained. These recordings have not been analyzed yet, but a preliminary investigation indicated that several impulses were captured. Recordings of the special NRL transducer have been obtained and sent to NRL. This method of measuring pressure induced self-noise of transducers was successful, in spite of the unrelated problems which were encountered. The facilities at Pend Oreille are adapted to these kinds of tests.

For future tests of this type, other methods of lowering and raising the tow body and/or transducers should be investigated. The tow body worked very well to carry the transducers and monitor hydrophones, but a more suitable winch system needs to be found. Good measurements can be obtained by the winch on the barge, but rapid pressure changes are not possible.

7.4. PLANS

Since Task F-1, Noise and Vibration, will no longer be a part of the STRIP program, many of the plans for FY80 will be dependent upon the direction and funding of the new Sonar Transducer Extraneous Noise Program. However, the remaining milestones will be completed for STRIP as follows:

- Completion of report TN 657 (October 1979)
- Informal report on pressure release materials self-noise (October 1979)

For FY80 the objectives are:

- Write software for computer analysis of digitized transducer and extraneous noise transients in terms of peak voltage (pressure), total energy, and energy spectral density.
- Compare the voltage (pressure) threshold test with the energy detectability criterion developed by NOSC.
- Develop test methods and procedures to prevent extraneous noise from being counted as transducer noise.
- Review and evaluate existing transducer self-generated noise criteria to help set standards for measurements to qualify transducers for submarine use.
- Develop test methods and procedures, based upon defendable criteria for allowable emitted energy, and apply these to selected transducers.
- Develop a method for calibrating the transfer-function between radiated and electrical outputs for selected transducers.
- Isolate and analyze selected transducer pressure release components for self-generated noise potential.

8. TASK G-1 - SLEEVE-SPRING PRESSURE RELEASE MECHANISM

A. M. Young - NRL-USRD and
R. L. Smith, Texas Research Institute, Inc.

8.1. BACKGROUND

Some transducers in use by the fleet have been found to emit extraneous electrical and acoustical noise as a function of changing hydrostatic pressure. The primary source of the noise is believed to originate in the pressure release mechanism of the transducers. Interim fixes have been implemented, but final solutions require the development of new pressure release mechanisms.

8.2. OBJECTIVES

The objectives of this task are to develop, fabricate, test, and evaluate an alternative pressure release mechanism. The new pressure release mechanism will be in the form of a slotted metal sleeve spring and will be retrofitted into the TR-155 transducer for test and evaluation.

8.3. PROGRESS

The sleeve-spring pressure release mechanism developed by Texas Research Institute, Inc. has been installed in six TR-155F transducers. Five of the retrofitted transducers have been subjected to the 5000 pressure cycle test at NWSC-Crane. Four of the transducers tested passed while one was judged to have failed the test. Problems with a noisy valve have made the data on the one failure suspicious and that data is being reexamined. The final report documenting the development, analysis, and transducer modifications has been received from TRI. The only work remaining on this task is the completion of the acoustic evaluation of the retrofitted transducer. The required measurements are scheduled for the Anchoic Tank Facility at NRL-USRD during the second week in October 1979.

8.4. PLANS

The noise test results, the acoustic measurements and the TRI report will be combined into a single final report on this task.

9. TASK G-2 - TEST AND EVALUATION

A. M. Young - NRL-USRD

9.1. BACKGROUND

The improvements in engineering developments, the development of new test methods, and the new specifications and standards achieved must be utilized to assemble, test, and evaluate prototype transducers so that all implications of proposed changes will be known before introduction to the fleet.

9.2. OBJECTIVES

The general objectives of this task are to evaluate new engineering development transducer projects and to provide quantitative alternatives for solving problems encountered in the operation of fleet sonar systems. Specific objectives for FY79 are as follows:

- Determine the feasibility of replacing silicone fluid in operational transducers on a class-by-class basis.
- Determine the correlation between measurements of noise made in small tanks and those made in a free field.
- Evaluate the sleeve-spring pressure release mechanism for extraneous noise and pressure independence of acoustic performance.

9.3. PROGRESS

9.3.1. Two TR-122 transducers containing silicone oil were received from the Transducer Repair Facility at Portsmouth Naval Shipyard, Portsmouth, NH. The operating characteristics of the transducers will be measured with both silicone fluid and castor oil used as the transducer fill-fluid. The measurements will be made in accordance with the Compendium of Test Requirements and Operating Characteristics for NAVSEA Sonar Transducers. The two sets of measurements will be compared to determine if any differences exist in the operational performance of the units.

The TR-122 transducers containing silicone oil have been measured in the Lake Facility at NRL-USRD. The measurements indicate that neither of the units meet the published specifications. This will not, however, affect the validity of the comparison measurements with castor oil which will follow next.

9.3.2. In order to determine the correlation between noise measurements made in small reverberent tanks and the free-field, a small impulse source has been installed in a TR-155 transducer. With the transducer exposed to various acoustic boundary conditions, the impulse source is excited by a very narrow pulse while the output voltage of the TR-155 ceramic stack is monitored by a spectrum analyzer. Initial measurements made at NRL-USRD look promising.

The transducer and instrumentation were transported to Lake Pend Oreille for free-field measurements. Upon successful completion of the measurements, the equipment was returned to NRL-USRD to repeat the measurement in the environment of a closed tube. Upon receipt, the modified transducer and the pulse generator were both found to have been damaged in shipment. The pulse generator has been repaired, but a new impulse source is required to repair the transducer.

9.3.3. Five of the TR-155 transducers retrofitted with the TRI sleeve-spring pressure release mechanism have undergone noise tests at NWSC-Crane. Four of the transducer passed while a noisy system valve has made the data on the one failure suspicious. That data is being reexamined. The five transducers are scheduled for acoustic tests at NRL-USRD during the second week in October 1979.

9.4. PLANS

- The silicone fluid in the TR-122 transducers will be replaced with Baker dB Grade castor oil and the measurements repeated. A final report will be completed by the end of next quarter.
- A new impulse source is being fabricated and installed in the TR-155 transducer. The correlation measurements will be repeated at NRL-USRD with the repaired transducer. A final report will be completed by the end of next quarter.
- The acoustic evaluation of the TR-155 transducers with the sleeve-spring pressure mechanism will be complete in October 1979. The noise test data, acoustic data, and the TRI developmental report will be combined into a single report to document this task.

DISTRIBUTION LIST
for
Sonar Transducer Reliability Improvement Program
(STRIP)

Commanding Officer
Naval Coastal Systems Center
Panama City, FL 32407
ATTN: Code 750A, R.L. Cook
Code 753, R. Lovejoy
Code 790, D.F. Folds

Officer-in-Charge
Civil Engineering Laboratory
Naval Construction Battalion Center
Port Hueneme, CA 93043
ATTN: Code L43, J.V. Wilson

Commander
Naval Electronic Systems Command
Washington, DC 20360
ATTN: Code 320, Ms. J. Bertrand

Commander
Naval Ocean Systems Center
271 Catalina Blvd
San Diego, CA 92152
ATTN: Code 712, D.L. Carson
Code 712, J. Kinnison
Code 7122, J. Wong
Code 7122, Dr. R.R. Smith
Code 7123, C. Bohman
Code 724, Dr. G.E. Martin

Commanding Officer
Naval Research Laboratory
Washington, DC 20375
ATTN: Code 2628 (20)
Code 2628 (12 for DDC)
Code 8000

Commander
Naval Sea Systems Command
Washington, DC 20362
ATTN: SEA06H5-21, Ms. D.G. Bagley
SEA63R-12, C.C. Walker
SEA63XT, R.E. Heaney
SEA63XT-1, C.A. Clark (3)
SEA63XT-2, P. Greenhaus
SEA63XT-4, T.G. Martin
SEA05N/6107B4D,
J. Pratchios
SEA05H, S. Blazek

Transducer Repair Facility
Mare Island Naval Shipyard
Vallejo, CA 94592
ATTN: C. Porterfield
F. Peglow

Transducer Repair Facility
Pearl Harbor Naval Shipyard
Pearl Harbor, HA 96860
ATTN: Code 270.3, R. Shigeta

Transducer Repair Facility
Portsmouth Naval Shipyard
Portsmouth, NH 03804
ATTN: Code 216.11 Type Desk (2)
(A. Theirrien)
(E. Comeau)

Commanding Officer
Naval Weapons Support Center
Crane, IN 47522
ATTN: Code 70553, D.J. Steele
Code 70553, D. Moore

Superintendent
Underwater Sound Reference
  Detachment
Naval Research Laboratory
P.O. Box 8337
Orlando, FL 32856
ATTN: Code 8200
      Code 8270
      Code 8275 (5)
      Code 8277 (4)
      Code 8278
      Code 8280
      Code 8215.2 (5)

Commanding Officer
Naval Underwater Systems Center
New London Laboratory
New London, CT 06320
ATTN: Code 316, Dr. C.H. Sherman
      Code 316, R. DeAngelis
      Code 316, T. Mapes
      Code 316, R. Vogelsong
      Code 316, C. LeBlanc
      Code 316, C. Olds

Ametek Straza
790 Greenfield
El Cajon, CA 92022
ATTN: H. Lewis
      E. Barnes
      R. Simmons

Applied Physics Laboratory
University of Washington
1013 NE 40th
Seattle, WA 98105
ATTN: Dr. C.J. Sandwith

General Dynamics
Electric Boat Division
Groton, CT 06340
ATTN: E.C. Hobaica
      R. Haworth

Hazeltine Corporation
115 Baystate Drive
Braintree, MA 02184
ATTN: G.W. Renner

Man Tech Corporation
Century Bldg, Suite 103
2341 Jefferson Davis Highway
Arlington, VA 22202
ATTN: S.S. Shimomura

Submarine Signal Division
Raytheon Co.
P.O. Box 360
Portsmouth, RI 02871
ATTN: N. Serotta, K_{33}
      Transducer Program
      Manager
      D. Ricketts, Consultant
      Design Engr. Lab.

Sperry Gyroscope Division
Division of Sperry Rand Corp.
Marcus Avenue
Great Neck NY 11020
ATTN: G. Rand, MS D-18

Texas Research Institute, Inc.
5902 W. Bee Caves Road
Austin, TX 78746
ATTN: Dr. J.S. Thornton (2)

Department of Civil Engineering
University of Utah
Salt Lake City, UT 84112
ATTN: Dr. B. Hufferd

MAR, Inc.
1335 Rockville Pike
Rockville, MD 20852
ATTN: Dr. W. Cramer

TRACOR, Inc.
Systems Technology Division
1601 Research Blvd
Rockville, MD 20850
ATTN: P. Flannery
B. McTaggert
J. Guarnieri
J. McClung

Honeywell, Inc.
Marine Systems Center
5303 Shilshole Ave., NW
Seattle, WA 98107
ATTN: C. Sheets

Potomac Research
P.O. Box KK
McLean, VA 22101
ATTN: P. Watson

MED

80